Science and Engineering at Yale.*

* A Guide to Undergraduate Research, Teaching, and Resources
World-class research and undergraduate education come together at Yale.
Science and Engineering Leadership in an Age of Opportunity

Scientists and engineers ask profound questions about the way things work. Here you will find innovative and creative leaders who push forward for answers, combining their pioneering research with the special capacity for teaching that has always been treasured at Yale.

We seek science and engineering students who want to make a decisive impact on society, and we will prepare you to manage the explosion of knowledge taking place in every important domain of research. Whether you plan to live on the frontiers of astrophysics or geophysics, life sciences or nanotechnology, you owe it to yourself to investigate Yale science and engineering.

Richard C. Levin, President of Yale University
Research with a capital “R” is about discovering something that nobody else has ever known. Yale undergraduates have that opportunity, since so many are doing their own research as early as the summer after their freshman year. The process of doing real science here is a bit like an apprenticeship, where students learn by doing, from professors, other students, and other scientists. While working with and learning from scientists at the forefront of some of today’s most exciting research, they become part of the world’s scientific community.

Axel Schmidt

Hometown Pittsburgh, PA
Major Physics Intensive. (The Physics major has two tracks: B.S. and B.S. Intensive. The latter is designed for students who want to continue on to graduate school, while the former offers more flexibility for students who want to complete the pre-med curriculum, double-major, or combine physics with another field like philosophy or astronomy.)

Extracurriculars Purple Crayon improv comedy, intramural sports, Peer Health Education

Why Yale “I chose Yale over a more technical university because I wanted a peer group that had a broader range of academic interests. I also wanted to be taught English, history, and music by professors who were leaders in those fields as well. If I were to make that choice again knowing what I know now, I would choose Yale for those reasons but also because at Yale, science majors are a little less common. We get special treatment for it. I was given a huge amount of support—academic and financial—to pursue research from the moment I got here. That has been the most valuable thing that Yale has offered.”

Post-Yale Plan “I’m headed to graduate school next year, to get a Ph.D. in physics. I haven’t made up my mind about where I’m headed, but I did get into MIT, Duke, Columbia, and Yale, so I have terrific options.”

Atomic Sweat

“Science is fundamentally about research. Regardless of how many classes you take or how much math you learn, you haven’t really done science unless you’ve poured sweat into your own lab project, computer program, or solar-powered robot. I had the tremendous opportunity to start working in a laboratory the summer after my freshman year, and in that time, I found that I love doing science. Research wasn’t about grinding out problem sets, but getting to tackle puzzles that nobody had ever seen or thought about before. It was about getting to ask the questions that I thought were interesting and important. On top of that, in classes from then on, I started thinking about questions like “How would one measure that in the lab?” Or “What kinds of experiments make use of this principle?”

“My research explores the structure of atomic nuclei. I am hoping to explain how removing neutrons from a heavy nucleus changes its structure from largely spherical and stable, to deformed and unstable. In my experiments, I measure the gamma-rays emitted from nuclei created in Yale’s particle accelerator, and then use these measurements to recover the excited states of these nuclei.

“In my sophomore fall, I went with the rest of my lab to a conference, and presented my research from the previous summer. Here I was, a sophomore, being asked questions by leaders in the field from all over the country. It was an amazing experience, and I made sure I went back to that conference every year after that. If I hadn’t done research, I never would have glimpsed the larger scientific community, and where I fit in.”

Axel
Driving Curiosity

“There’s something about going out and trying to answer a novel question, or collect new data on something that’s never been studied before, that’s so rewarding and makes me feel like I’m making contributions to something new. Lab research has been very important not only in giving me hands-on experience, but also in showing me that I enjoy it. Perhaps most importantly, I’ve learned that I can do research and that I’m less concerned about my prospects as a researcher in the future. The lab that I work in does terahertz (THz) spectroscopy, which is a kind of vibrational spectroscopy. The project I’m working on is the study of single-crystal and polycrystalline amino acids using this and another technique called Raman spectroscopy to look at collective vibrations of molecules in a lattice.

“Learning in a lab is so much more proactive than the classroom. Something is interesting, and so you go and learn about it. Your own interests drive your curiosity, which I find makes learning much easier.”

Benjamin Ofori-Okai

Bio-Prospecting

“Yale without my rain forest research would have been a very different place. Almost no one goes bio-prospecting for endophytes in the Amazon rain forest. So my mentor, Professor Scott Strobel, a world leader in understanding catalytic reactions triggered by RNA, knew the students in his ‘Amazon Rain Forest Expedition and Laboratory’ were likely to find things no one else had seen.

“What we discovered blew us away. We returned with ten species of fungal endophytes that we have been able to classify as an entirely new genus. Even more exciting for me was that, once we got back to the lab, I discovered that an extract from one of these fungal endophytes reduces inflammation in human tissue. A subsequent analysis of the molecule revealed it to be an inhibitor of apoptosis, or programmed cell death. It may also lead to drugs that could prevent preterm birth—something we’re continuing to investigate both in the lab and with further prospecting in Ecuador.

“I’ve had multitudes of opportunities to present this research in all sorts of settings, including informal lab meetings, undergraduate symposia, professional conferences, general public and classroom talks, and even a talk for the president of the University and his council on international affairs. In addition, I have been working on publishing my results in scientific journals. In all of these endeavors, I have had support and encouragement from my faculty advisers.

“My research experience has absolutely been an invaluable and integral part of my undergraduate education here. It’s also had a direct impact in defining my future goals.”

Sunjin Lee

Sunjin Lee
Hometown Vancouver, WA
Major Molecular Biophysics and Biochemistry
Extracurriculars “Aside from scientific research, I love to pursue my interests in classical music. I play oboe with a couple of different chamber groups and orchestras, and also enjoy playing in pit orchestras for operas.”

Why Yale “Beautiful campus, amazing people, and countless opportunities for anything and everything you could possibly be interested in. Yale also had one of the best financial aid packages among all of the schools I had to choose from.”

Post-Yale Plan “I will be pursuing a career in translational research, which bridges gaps between basic science and clinical medicine.”

Opposite page:
Benjamin K. Ofori-Okai
Hometown Albany, NY
Major Chemistry
Extra Curriculars Yale Anti-Gravity Society, Pierson College Master’s Aide, Pierson College Buvtry, Association of Undergraduate Chemistry Students, Society of Physics Students

Why Yale “I chose Yale because I can dedicate the rest of my life to science, but not necessarily to all the other things I am interested in. Some of my greatest learning has come from the conversations with my friends who major in history, philosophy, and classics.”

Post-Yale Plan “I am going to graduate school to earn my Ph.D. with the goal of becoming a professor.”
Green Workout

"Having the opportunity to solve a real-world problem with your own design, and receive funding and faculty guidance to do it, is pretty phenomenal. For my senior project I worked with associate professor of Electrical Engineering Hür Köser. The project was a great opportunity to have hands-on experience dealing with all the conflicting aspects of a real project. The idea I had was to harness the energy generated by a stationary exercise bike to charge small electronic devices like iPods and cell phones. We had to think about the design, trying to make something robust, fault-proof, and at low cost.

"Most stationary exercise equipment already has a small alternator fitted to it that generates electricity from the user’s motion to power the control panel. But this process uses only about one-tenth of the generated electricity. A regular exercise bike could produce 200 to 250 watts of power—more than enough to power a multitude of small electronic devices. In fact, if expanded to all the machines in the gym, enough energy would be harnessed to power gym light fixtures, televisions, and other utility devices—an eventual goal of the project.

"Since the initial prototype I have been able to perfect the design, build self-contained circuit boards, and mass-manufacture them. With the help of friends and lab members, we recently installed the chargers on all forty compatible machines in the Yale gym. Normally all the power generated would be dumped in a load. But through our approach we can extract the energy before it is dumped and do something useful with it."

Henrique Rocha (center), associate professor Hür Köser (left), and graduate students Muhammet Uncuer (right) and Tolga Kaya (far left)

Getting Your Hands Dirty

"When I was a sophomore, I was looking for a campus job. I went to the chair of the Chemical Engineering department and asked what was available. He told me that the policy of the department was to give a research position to every student who wanted to participate. That’s a pretty incredible thought—Yale has the resources and the faculty support to encourage every undergrad to do research.

"I worked with Robert McGinnis on forward osmosis desalination for two years. Rob, a Yale doctoral student in Environmental Engineering, is revolutionizing the industry. While at Yale he started a company that uses the new technology he’s developed. I feel lucky to have been a part of that. Beyond the intellectual benefits of participating in a working laboratory, I learned about the importance of humility in research. Rob and I were doing important work that I truly believe will be a viable technology within the decade. It has the potential to change the way we think about potable water. However, our experiments could be thwarted by a simple leak. I spent so many hours clambering over our prototype, tightening bolts."

"That’s what research is all about—having the intellectual prowess to problem-solve in an efficient and innovative way, but also having common sense and a willingness to get your hands dirty. Persistence is important."

Lee Christoffersen

Hometown Littleton, CO

Major Environmental Engineering, Intensive and Geology and Natural Resources

Extracurriculars Research assistant, tour guide for the School of Engineering & Applied Science, sustainability coordinator, student chapter of Engineers Without Borders, founding member of Yale’s chapter of Society of Women Engineers

Why Yale "I thought I wanted to study astrophysics. When I visited Yale, the college set up a personal meeting with Professor Meg Urry. This renowned scientist took me out to lunch! I’ve had the opportunity to take classes in the humanities and social sciences—classes taught by really incredible professors. Scientific fields are inextricably tied to politics, the economy, and social values. It’s vital to understand these other factors."

Post-Yale Plan "I am interested in the environmental aspect of the mining industry. I’ve had three summer internships focused on the topic. I’ve worked on the design of a tailing storage facility, environmental and social impact assessments, closure plans, and acid rock drainage treatment."

Opposite page:

Lea Christoffersen

Hometown Belo Horizonte, MG, Brazil

Major electrical Engineering

Extracurriculars Yale Student Investment Group, YEDT Aerial Robotics

Why Yale "Brilliant and diverse student body, extremely renowned professors and departments, exceptional financial aid packages, and a small city so it was easier to adapt and make friends coming from a foreign country."

Post-Yale Plan "I have been offered a position in investment banking in New York City that I will begin after graduation. Later on, I plan to try to get into politics back in Brazil."
Innovation Incubator.
(Yale scientists changing the world)

Translating basic research into new technologies that advance health and welfare has been part of Yale’s “DNA” for centuries, and the pace of innovation here continues to accelerate dramatically. Today’s Yale inventors are leading the way in science, medicine, and engineering through breakthrough research in nanomaterials, genetics, computational biology, biomedical engineering, and sustainable energy production. While “interdisciplinary” is a buzz word these days, the concept of bridging traditionally disparate fields, including biology and the life sciences, physics, chemistry, geology, mathematics, and engineering, is at the heart of this university’s scientific endeavors. Here are just a few of our faculty and projects at the forefront of discovery and making a real-world difference.

**Portable Disease Detectors**

Yale scientists have created nanowire sensors coupled with simple microprocessor electronics that are both sensitive and specific enough to be used for point-of-care disease detection. Using such detectors, says Tarek Fahmy, Yale associate professor of Biomedical Engineering, doctors could immediately determine which strain of flu a patient has, whether or not there is an infection, or what strain of tuberculosis or E. coli bacteria is present. Currently, there are no electronic point-of-care devices available for disease detection.

Fahmy and his colleagues see a huge potential for the system in point-of-care diagnostic centers in the U.S. and in developing countries where health care facilities and clinics are lacking. He says it could be as simple as an iPod-like device with changeable cards to detect or diagnose disease. Importantly, the system produces no false positives—a necessity for point-of-care testing. “Instruments with these sensitive could also play a role in detection of residual disease after antiviral treatments or chemotherapy,” said Fahmy. “They will help with one of the greatest challenges we face in treatment of disease—knowing if we got rid of all of it.”

**Creating a Quantum Computer—One Artificial Atom at a Time**

Robert Schoelkopf and Michel Devoret are creating basic building blocks for a future quantum computer. These computers of tomorrow, researchers say, will store, process, and transfer huge amounts of information unimaginably quickly and in spaces that are almost inconceivably small—visible only with an electron microscope. The two Applied Physics professors are among an elite group of experimentalists, working at the level of single microwave photons, tiny packets of light energy.

Schoelkopf is a former NASA engineer and Devoret was a director of research at the French Atomic Energy Commission before moving to Yale. At Yale, they are combining novel new designs for superconducting “artificial atoms” with tiny superconducting cavities to create electrical circuits that realize “microwave quantum optics on a chip,” said Steven Girvin, a Yale theoretical physicist who collaborates on their project. The two scientists have managed to squeeze the tiny photons into ultra-small cavities on a chip, akin to a regular computer microchip. They’ve also squeezed “artificial atoms” that can act as quantum bits—units to process and store quantum information. The tiny packets of energy from the microwaves interact with these small atoms a million times more strongly than if the atoms had been in a standard bigger cavity.

The cavity acts as a “quantum bus” allowing quantum information to be sent from one atom to another, forming the basis of a new architecture, the beginnings of quantum computers can be built, “they can very efficiently break certain types of codes.”

**New Class of Antibiotics**

After imagining and “inventing” riboswitches, RNA sequences that can bind and act as sensors in various molecules, Ron Breaker, Henry Ford II Professor of Molecular, Cellular, and Developmental Biology and professor of Molecular Biophysics and Biochemistry, discovered natural riboswitches in the genomes of microorganisms. Riboswitches act as major control elements for gene expression. Yale start-up BioRelix was established to use these genetic elements for designing a new class of antibiotics.
**Saving Lives Through Genetics**

An amazing revolution is under way as it becomes possible to rapidly and cheaply sequence large portions of the human genome. The most common fatal diseases have underlying inherited components. Rapid advances in molecular genetics now make it possible to quickly and easily identify the genetic variants underlying these diseases, promising to transform the diagnostic and therapeutic approaches to these disorders.

Dr. Richard Lifton, chair of the Department of Genetics at the Yale School of Medicine and professor of Medicine and of Molecular Biophysics and Biochemistry, is one of the world's leading experts and advocates of genome-wide analysis of human populations to find genetic links to diseases. He and Yale neurobiologist Dr. Murat Gunel recently discovered a genetic link to brain aneurysms, and their findings could lead to new tests to spot those at greatest risk. In addition, a post-doctoral fellow in Lifton's lab, investigating the genetic causes of blood pressure variation, recently identified a previously undescribed syndrome associated with seizures, a lack of coordination, developmental delay, and hearing loss. The work illustrates the power of genetic studies not only to find causes of chronic ailments, but also to identify a common cause in a seemingly unrelated set of symptoms in different parts of the body.

“Our ability to unequivocally and rapidly define new syndromes and their underlying disease genes has progressed dramatically in recent years,” says Lifton. “A study like [the one identifying the new syndrome] would have taken years in the past, but was accomplished in a few weeks by a single fellow in the lab.” He says he hopes the research will not only help doctors identify people with the new syndrome but also lead to greater recognition that patients with apparently complicated syndromes may often have simple underlying defects that can be understood.

Ultimately, the ability to identify genes associated with human disease paves the way for “personalized medicine” in which treatments can be tailored to an individual's specific genetic makeup.
Green Chemistry in Policy and Practice

Yale is easily one of the foremost centers in the world for green chemistry and green engineering. Indeed, “the father of green chemistry” is Yale chemist Paul Anastas. In 1991, when Anastas served as chief of the Environmental Protection Agency’s chemistry branch, he coined the term “green chemistry” to describe the design of safer chemicals and chemical processes to replace the use of hazardous substances. Later he led Yale’s Center for Green Chemistry & Green Engineering before being tapped by President Obama to head the EPA.

One of Yale’s next generation of innovators in green chemistry is Julie Zimmerman, assistant professor jointly appointed to the departments of Chemical Engineering and Environmental Engineering and Yale’s School of Forestry & Environmental Studies. Through her engineering research, Zimmerman is working toward the next generation of products, processes, and systems based on efficient and effective use of benign materials and energy to advance sustainability. To enhance the likelihood of successful implementation of these next-generation designs, she also studies the effectiveness and impediments of current and potential policies developed to advance sustainability. Together these efforts represent a systematic and holistic approach to addressing the challenges of sustainability to enhance water and resource quality and quantity, to improve environmental protection, and to provide for a higher quality of life.

Zimmerman and her colleagues recently identified tradeoffs in the use of green alternatives in the metalworking industry and found that a switch from water-based to gas-based metalworking fluids systems is a move toward more sustainable manufacturing overall. She and colleagues also proved that certain countries and some U.S. states stand to benefit from the use of compact fluorescent lighting in the fight against global warming, while the use of such lighting in some areas could actually be more harmful to the environment.

Hunting Dark Matter with the World’s Largest Atom Smasher

The Large Hadron Collider—the world’s largest atom smasher—was built in collaboration with thousands of scientists from hundreds of universities across the globe, including Yale. Keith Baker and Paul Tipton, both professors of Physics at Yale, use the Large Hadron Collider to investigate dark matter—that elusive substance which neither emits nor absorbs light but accounts for approximately 25 percent of the universe’s mass. Specifically, Baker and Tipton are searching for a new particle responsible for dark matter. Whether dark matter is made up of ordinary particles has been one of the most hotly debated questions in cosmology in recent years. The two particle physicists carry out their experiments using ATLAS, one of two general-purpose detectors at the Large Hadron Collider located at the CERN laboratory near Geneva, Switzerland. The Large Hadron Collider opened in 2008 and took nearly fifteen years to complete. Physicists use the Large Hadron Collider to search for the hypothesized, but not yet observed, Higgs boson. Dubbed the “God particle,” the Higgs boson explains why every other particle has mass and would provide the missing link in the Standard Model—our current theoretical understanding of particle physics.
A New Class of Metals

Jan Schroers, associate professor of Mechanical Engineering, and his team have been exploring a class of materials called amorphous metals or bulk metallic glasses, BMGs, which can be molded like plastics and are more durable than silicon or steel. The team has created a process for making computer chips at the nanoscale that may revolutionize the industry. More recently Schroers has determined that BMGs have important biomedical applications—from stents to bone replacement. He and Themis Kyriakides, associate professor of Pathology and Biomedical Engineering, are working together to put the unique processibility of BMG to the test. Their work targets three applications: bone replacement, soft tissue implants like stents, and surface patterning to program cellular response (synthetic membranes such as artificial kidneys).

Unlike most metals, BMGs have a tendency to avoid crystallization when solidified. It is their “amorphous” structure that yields many advantages including remarkable properties of high strength (three times that of steel), elasticity, corrosion resistance, and durability—all of which exceed the properties of currently used biomaterials. Most notable, however, is their unique processibility that allows them to be molded like plastics with nano-scale precision and complex geometries. This processing capability has only come with the recent emergence of thermoplastic forming, which decouples the fast-cooling process from the molding process, allowing the time needed for precision net-shaping.

Of course, the selection criteria for biomaterials include more than favorable mechanical and chemical properties and ability to be precisely shaped—biocompatibility is an absolute necessity. “We knew we had a superior material over currently used implant materials, and we now have found out that we can indeed put it in the human body,” says Schroers.

Natural Proteins by Design

Scientists dream of the day when they can create designer proteins capable of inhibiting harmful interactions, modifying substrates, or guiding cellular machines to where they are needed within the body. Though that dream may be far down the road, Alanna Schepartz, the Milton Harris Professor of Chemistry and of Molecular, Cellular, and Developmental Biology, took an important first step forward when she and her team created the first synthetic protein in the lab. “Creating artificial proteins is somewhat of a holy grail,” says Schepartz. “A fair number of people thought it would be impossible to synthesize a molecule that could come close to behaving like a natural protein that has benefited from billions of years of evolution.”

Schepartz’s team created a short ß-peptide that assembles into an “octameric bundle” shape that exhibits all the traits of natural bundle proteins, but with some additional potential benefits. “Unlike natural peptides and proteins, ß-peptides are not broken down by enzymes, not altered significantly by metabolism, and seem not to jump-start the immune system the way a foreign natural protein can,” Schepartz says. That means scientists may one day be able to design drugs with all the functions of natural proteins, but which won’t be broken down by the body.
Building the Future.
(Investing $1 billion in new facilities and renovations)

A new era of discovery is changing lives for the better in every part of the globe—and Yale is prepared as few institutions are to advance knowledge and apply it to today’s greatest challenges. We are investing significant resources in the sciences and engineering including the addition of a new West Campus of 500,000 square feet of research laboratories and interdisciplinary institutes. On central campus the University is approaching completion of a decade of far-reaching renovation and expansion of science and engineering facilities. The $1 billion program has led to massive new construction. In addition to the three buildings illustrated here, Yale recently completed the Class of 1954 Environmental Science Center, the Class of 1954 Chemistry Research Building, and a number of laboratory facilities at the School of Medicine. The program also provides extensive upgrades to existing classroom and laboratory spaces.
The Yale Center for Microelectronic Materials and Structures (µELM) This facility includes a 2,600-square-foot class 100 Cleanroom that contains equipment for solid state device fabrication, including facilities for photolithography, wet chemical etching, oxidation, diffusion, thermal evaporation, sputtering, reactive ion etching, chemical vapor deposition, and other thin-film processes.

West Campus Already home to more than 800 science, math, and engineering labs, in 2007 Yale took what its president called “a once-in-a-century opportunity.” The University acquired a 136-acre pharmaceutical research park located on the border of the neighboring communities of West Haven and Orange, Connecticut. Called “West Campus,” facilities include more than 500,000 square feet of research laboratories, which will eventually house five interdisciplinary institutes in some of the most critical areas of science: chemical biology, microbial diversity, cell biology, systems biology, and cancer research.

The acquisition of West Campus has increased by half the space available to Yale for teaching and research (below).
As a student at Yale you are situated on central campus, midway between Science Hill to the north, with its laboratory and classroom buildings, and the School of Medicine to the south. Both are within walking distance. Altogether that means hundreds of labs, each pursuing different kinds of research and easily accessible to where students live and work. Here you will find literally any kind of research that may interest you.

Walking Times
Bass Center to Sloane Physics Lab: 3 min.
Gibbs Labs to Osborn Memorial Labs: 4 min.
Old Campus to Becton Center: 8 min.
Kline Biology Tower to Cross Campus: 10 min.
Malone Center to School of Medicine: 15 min.
Mentoring Future Leaders.
(Scientists and engineers talk about teaching)

A remarkable commitment to and capacity for teaching undergraduates sets Yale apart from other great research universities in the world. To get a good sense of just how integrated undergraduate teaching and world-class research are here, one only needs to compare the overlap in faculty names between those making research breakthroughs and those listed in the Yale course catalog. Faculty say some of their best research ideas are often sparked in the classroom. Students say they are amazed by the incredible access they have to people who really are changing the world through science and engineering. We asked some of these great teachers and researchers why Yale is an extraordinary place to study and practice science and engineering.

Q What sets the Yale science and engineering experience apart from those at other research universities?

Kyle Vanderlick “The very things that make Yale a great place to conduct research also make the University a great place to learn. Students have access to world-class scholars, state-of-the-art facilities, and a collaborative culture supporting exploration and personal development. In short, engineering is about pushing the boundaries of what mankind can do through technological innovation. This simply cannot be done without a broad understanding of humanity, nor without the rich set of communication skills necessary to convey new and complex ideas. This is what engineering at Yale is all about.”

Mark Saltzman “There’s something different about rigorous training in engineering embedded in a liberal arts tradition. One of the features of a liberal arts education is that you’re required to take courses in all sorts of different things. For instance, we think it’s important that our students study a foreign language as well as the social sciences. Taking different kinds of classes creates a different sort of curiosity. Our students bring that curiosity to the kinds of questions they’re asking and trying to answer in science classes and engineering research labs. It’s certainly a different experience than at other places I’ve been where, if you’re an engineering or science major, you’re studying the same kinds of things in the same kind of way that other students around you are studying. You’re also living with other science and engineering majors. Here, students are living among future historians, future economists, English majors, and political science majors, all bringing their own brands of thought to questions and ideas.”

Mark Saltzman “There are 11 faculty members in Biomedical Engineering and we have 20 to 25 majors each year, so nobody is anonymous. Every student does research. They all do a significant senior project. They all take classes with most of the faculty during their time here. At graduation when I meet their parents, I know something significant about each student. That’s pretty rare.”

Meg Urry “What we teach in science classes are tools and a way of thinking. The tools are basic concepts like gravity, forces, acceleration, motion, thermodynamics, and fluids that are manifested everywhere in nature. In the lab, we apply those concepts to different aspects of nature. In my own
Meg Urry  “It’s like the difference between learning to speak French well (understanding basic physics concepts) and reading French literature (working in a physics lab). You have to do the first in order to do the second.”

Charles Schmuttenmaer  “Classroom learning is absolutely essential for success in research. Like Meg, I think of it as filling a toolbox with all sorts of tools. Some are rather generic, like hammers and saws, and some are quite specialized, like a pulley puller or a plumber’s basin wrench. Not every project will need every tool, but the more you have in your toolbox, the better equipped you’ll be to tackle something new. The daily practice of science is characterized by creatively and innovatively solving research problems with all the tools at one’s disposal. By definition, you’re doing things in a research setting that have never been done before. That’s what makes it research, after all. I think the creative aspects of scientific research are often overlooked or underestimated.”

Mark Saltzman  “That is the obvious difference—that in the classroom you’re talking about accumulated knowledge and ideas that have been tested and known in lots of different ways, so it’s not so controversial or open-ended. Almost everything you do in a research laboratory is open-ended and there is not any one way to get from point A to point B. Sometimes you don’t even know what point B is. You’re probing to find it in different ways and you don’t know what the outcome will be.”

Joan Steitz  “The old idea of a scientist being an iconoclast who has a brilliant idea and then goes into the lab and does an experiment all by him or herself, looks at the data, and then comes to a lofty conclusion is so faulty. Students here learn how communal the scientific enterprise is.”

John Harris  “We are looking for students who are excited about science and are motivated to learn new concepts and make new discoveries. They need to think independently and for the benefit and success of the research project and team. In terms of skills, they need to have the ability to understand new concepts, to clearly articulate questions and ideas, and to communicate their questions, ideas, and concepts to others.”

Meg Urry  “They need to be smart, motivated, persistent, and good communicators. No one of those qualities is sufficient in and of itself—they need all four. They have to want to discover new knowledge; they have to master the tools of discovery; they need to be able to finish a project, however…”

Charles Schmuttenmaer  “Beyond a strong background and ability in math and science, I look for people who can solve problems independently while working with others on a team. It is not a situation where I have all the answers and dole out my knowledge to them. I look for people who are resourceful. People who leave no stone unturned when confronted with data that doesn’t seem to make sense. The sooner young researchers learn that the information they need will not be neatly packaged in some particular textbook, the sooner they will be successful.”

John Harris  “Communication skills are essential. In experimental science you’re starting from a tradition of knowledge. From there you put together a hypothesis and test that hypothesis. But this is always done by people talking to each other, people evaluating each other’s data. Yale is particularly good at teaching students how to communicate at a high level with faculty, postdocs, and research subjects.”

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many snags they may encounter; and they need to be able to communicate their results to others, preferably in an articulate and exciting way.”

Q Based on your personal experience of being an active research scientist, what do you think students need in order to be successful?

Joan Steitz “What every scientist who succeeds comes to appreciate is that there is really something very special about discovering something — no matter how small it is — that nobody else has ever known. When you first develop that film or look under the microscope and discover something new, you’re the only person in the universe with that knowledge. You have to be turned on by the curiosity to ask new questions, and by the joy of finding the answers. As an undergraduate, because my role in labs had always been helping someone else on that person’s project, I didn’t understand how exciting it was to have my own project. I became completely hooked after that. In my lab, I make sure every undergraduate has his or her own project from the start. Even though they are working closely with somebody who knows more and who obviously cares about their project succeeds or not, it is completely up to the undergrad as to whether that project succeeds. It’s theirs.”

Kyle Vanderlick “Engineering today at Yale is very different from its inception in the mid-1800s. We’re not building bridges, we’re curing diseases, cleaning and protecting our environment, computing at the quantum scale, and solving the energy crisis. More than an education in technological innovation, Yale engineering is a curriculum for leadership in the twenty-first century.”

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Kyle Vanderlick “Quantitative reasoning, teamwork, and the habit of breaking complex problems into manageable pieces — these are the skills needed to be a successful engineer. Engineering is a purposeful and powerful way of thinking. It prepares students for fulfilling careers in engineering right after college, but it is also a broad and foundational education that well serves students interested in business, medicine, law, and for an endless list of life pursuits in today’s technologically driven world.”

Mark Saltzman “I have a lot of faith in the power of human connection — that somehow people use the examples that they see in order to envision their own path. That is why it’s so important for working scientists and students to be in the classroom together. Students can get the facts from any number of places, but in the classroom they have human examples of interesting ways to approach problems, human examples of paths they might want to replicate in some way.”

Meg Urry “I agree. The process of doing science is a bit like an apprenticeship. We show them how to ask a question, how to find the answer, and then we help them learn to present their results to others. And along the way, I hope we also show them that professors are mortals, that our profession is one we love and enjoy, and that we can combine work with a full and satisfying life.”

W. Mark Saltzman
Goizueta Foundation Professor of Chemical and Biomedical Engineering, and Cellular and Molecular Physiology

Professor Saltzman is the founding chair of Yale’s Biomedical Engineering department. His research interests include drug delivery to the brain, materials for vaccine delivery, and tissue engineering; he has published over (continued in right column)
Paths to Success.
(From high school to Ph.D., mapping the routes)

Yale undergraduates studying science and engineering are ideally studying science and graduates trace the major position they are today.

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**Gregg Favolora**

**Hometown: Teaneck, NJ**

**Yale Class of 1996**

B.S. Electrical Engineering

M.S. Engineering Sciences

Harvard University 1998

**Current**: Founder and Chief Technology Officer, Actuality Medical, Inc.

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### #1 Pivotal Moment

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### Persistence and Patent

I knew what I was onto something. By the end of the summer after graduation, my projector was displaying 3D images of Homer Simpson's head, an air traffic scene, and the letter “Y.” This made believers out of a bigger circle of people and I earned a patent for the invention.

### It All Started at Yale

For my senior project as an electrical engineering major, I created a three-dimensional projection system. The system exploited the persistence of human vision by projecting one-dimensional images very quickly onto a rotating screen so that a viewer's eyes perceived an aggregate 3D image.

### Today

Some of the world's largest oil companies are interested in working with my company, Actuality, to help them analyze seismic data in their search for oil and natural gas. NASA and the United States military are also clients of Actuality, hoping to use the system for simulation and command and control. Most notably, hospitals nationwide are beginning to test Actuality's Perspecta system, which makes vast improvements in the way radiation oncology is carried out.

### Why Yale

Everything you hear and read about Yale's commitment to undergraduates is completely true. You get a front-row ticket to theory and practice. Best of all, your future opportunities, whether you become a professional engineer or not, really are right at your fingertips.

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### #2 Pivotal Moment

Things finally started to turn around. I met a journalist known for chronicling the happenings of Silicon Valley. After watching an image of the HIV virus rotating in space projected from my 3D prototype, he wrote an article for the *Wall Street Journal* on the invention and my difficulty finding funding. Soon I had so many offers I had to turn investors away.

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### Investor Search

A three-year investor search followed. It was the height of the dot-com boom. Investors were pumping huge amounts of money into the craziest of dot-com ventures, but no one was interested in work with three-dimensional images that could potentially help surgeons operate on cancer patients. Meanwhile, my parents were buying me groceries, and my team of engineers was living off McDonald's Bag of Burgers special—six for $3. Things looked bleak.

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“By the end of my time at Yale, I was on a first-name basis with much of the faculty. The Physics department chair always welcomed me into his office and was delighted to either listen to my concerns or support whatever new venture I was suggesting.”

Why Yale
(Before attending)
As a high school student, I participated in the Yale Physics Olympics. I was so inspired by the Yale professor who organized the event that I made a point of visiting him when I was looking at Yale for college. On my visit, I wandered into a nuclear physics seminar oriented toward grad students and professors. While I only understood a small part of the talk, I was fascinated by the “real” science being discussed. I still remember that the topic was how exotic nuclei were created in the universe.

Early Ambitions
I was lucky to be surrounded by science and scientists growing up. I can’t remember a time that I didn’t want to be a scientist. While it is clichéd, I want to do my part to unravel the mysteries of unanswered questions in science.

Why Yale
(After attending)
The friendly, approachable faculty always had time to talk to an undergraduate (or high school student). I had fantastic faculty research mentors like Professors Rick Casten and Eric Dufresne. Eric still checks in on me to see how I’m doing in grad school.

#1 Pivotal Moment
My year working with Professor Rick Casten in Yale’s Wright Nuclear Structure Laboratory – I gained a greater understanding of the scientific process and experienced presenting my work at a national conference.

#2 Pivotal Moment
Sophomore year, I was so inspired by a microfluidics presentation by a visiting professor that I went up to him afterward and asked for a summer internship. That internship led me to the field of soft condensed matter, which led me to two years in Yale professor Eric Dufresne’s lab. My time there had an enormous impact on my research career and my conception of myself as a scientist.

#3 Pivotal Moment
Motivated by my enjoyment of giving presentations, my love of learning new physics, and my goal of helping younger undergraduates ease their presentation anxieties – I started an undergraduate journal club.

Current Work
I am a Ph.D. candidate in Physics at Harvard. I work in soft condensed matter, specifically biophysics. My project is to study the dynamics of how viruses assemble from individual proteins.

Why Yale
I came to Yale when undergradate science was being re-invigorated through programs like Perspectives on Science. Seeing Yale’s interest in nurturing undergraduates in science appealed to me. Other schools also offered great programs, but Yale seemed most interested in me as a young scientist. My experiences later proved that to be true.

High School
I began looking at the world through the eyes of chemistry and physics, which was an empowering experience that drove me toward studying science later.

#1 Pivotal Moment
Physical chemistry freshman year exposed me to rigorous thermodynamics and quantum mechanics, opening my understanding of the world and the beauty of nature.

#2 Pivotal Moment
Working for my great undergraduate mentor, Charles Schmuttenmaer, in the Chemistry department was an important turning point for me. His curiosity and inquisitiveness showed me how interesting physical chemistry can be. His friendly and encouraging nature nurtured the genesis of my scientific efforts.

Grad School Dividend
I have a much larger breadth of knowledge than most other graduate students in my department, particularly because of my coursework and research at Yale. I was encouraged to take courses that spanned a wide range of scientific topics. That has paid large dividends down the line.

Novel Research
In my research group, I had my own project and worked individually under my adviser. I was not simply performing busywork for a graduate student. Professors at Yale take undergraduate education and research very seriously. They try to find a good niche for an undergraduate to contribute to novel research while learning an immense amount.

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My work in the Department of Chemistry at Stanford focuses on molecular dynamics in liquid phase systems using ultrafast spectroscopy.

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Bonus
Yale attracts very talented scientists who are also interesting people. You’re a full-fledged member of the scientific community—not an undergraduate underling.

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Yale Science & Engineering Primer.
(Schools, departments, majors, programs, facts and figures)

Approximately one-third of Yale’s entering class each year intends to major in the natural sciences, mathematics, computer science, or engineering. Our faculty of outstanding scholars in the sciences, mathematics, and engineering includes more than seventy members of the National Academy of Sciences. These faculty members conduct research in more than forty science and engineering disciplines. Undergraduates are involved in much of it.

Major Departments and Programs
Science and engineering majors are highlighted

- African American Studies
- African Studies
- American Studies
- Anthropology
- Applied Mathematics
- Applied Physics
- Archaeological Studies
- Architecture
- Astronomy
- Astronomy & Physics
- Biology
- Biomedical Engineering
- Chemical Engineering
- Chemistry
- Chinese
- Classical Civilization
- Classics (Greek, Latin, or Greek & Latin)
- Cognitive Science
- Computer Science
- Computer Science & Mathematics
- Computer Science & Psychology
- Computing and the Arts
- East Asian Studies
- Ecology & Evolutionary Biology
- Economics
- Economics & Mathematics
- Electrical Engineering
- Electrical Engineering & Computer Science
- Engineering Sciences
- English
- Environmental Engineering
- Environmental Studies
- Ethics, Politics, & Economics
- Ethnicity, Race, & Migration*
- Film Studies
- French
- Geology & Geophysics
- German Languages & Literatures
- German Studies
- Greek, Ancient & Modern
- History
- History of Art
- History of Science, History of Medicine
- Humanities
- International Studies*
- Italian
- Japanese
- Judaic Studies
- Latin American Studies
- Linguistics
- Literature
- Mathematics
- Mathematics & Philosophy
- Mathematics & Physics
- Mechanical Engineering
- Modern Middle East Studies
- Molecular Biophysics & Biochemistry (MB+B)
- Music
- Near Eastern Languages & Civilizations
- Philosophy
- Physics
- Physics & Philosophy
- Political Science
- Portuguese
- Psychology
- Religious Studies
- Renaissance Studies
- Russian
- Russian & East European Studies
- Sociology
- South Asian Studies*
- Spanish
- Special Divisional Major
- Theater Studies
- Women’s, Gender, & Sexuality Studies
- *May be taken only as second major

Special Programs
Perspectives on Science and Engineering is a year-long interdepartmental course that introduces selected first-year students with exceptional math and science backgrounds to faculty and their research disciplines. Perspectives students are offered stipends to support summer research in faculty laboratories.

STARS (Science, Technology, and Research Scholars) Since 1995, Yale’s nationally recognized STARS Program has promoted diversity in the sciences through mentoring, academic year study groups, and an original research-based summer program for freshmen and sophomores. Juniors and seniors have the opportunity to continue their research through the STARS II Program.

Graduate and Professional Schools
Graduate School of Arts & Sciences
School of Engineering & Applied Science
School of Forestry & Environmental Studies
School of Medicine
School of Nursing
School of Public Health
School of Architecture
School of Art
Divinity School
School of Drama
Law School
School of Management
School of Music
Institute of Sacred Music
Undergraduate courses taught by professors or lecturers (the remaining 7% are chiefly in foreign language and freshman English).

150
Over the last five years 150 faculty members have published research with undergraduates.

800+
Science, math, and engineering labs at Yale College and the graduate and professional schools.

70
Undergraduates each year for the last five years have co-authored published research.

95%+
Undergraduate science majors who do research with faculty.

1:1
Yale’s School of Engineering & Applied Science has approximately 60 professors and graduates approximately 60 engineering majors a year.

90%
Admission rate for Yale College graduates to medical schools (national average 49%).

90%
Students in all science disciplines routinely admitted to top graduate programs.

$1 Billion
In new monies for science, engineering, and medical research facilities since 2001

$1 Million
Funding for undergraduate science research fellowships in the most recent year.

$1 Million
More than 100 science program alumni who graduated in the mid-80s and early 90s are now science faculty members at top universities.

2,000+
Courses offered each year in 70 academic programs and departments.
Lives.

Freshman Diaries. Yale’s newest students chronicle a week in the first year and give some advice.

Anatomy of a Residential College. Yale’s residential college system is unparalleled and enhances the pleasure of attending Yale like nothing else. Far more than dormitories, our 12 residential colleges have been called “little paradises” — endowed with libraries, dining halls, movie theaters, darkrooms, climbing walls, ceramics studios, and many other kinds of facilities and each with its own traditions. Each college is home to a microcosm of the undergraduate student body as a whole. (For science and engineering majors this means that your friends will be actors and economists, musicians and linguists, artists and historians as well as biologists and physicists.) The residential colleges with their resident deans and masters, affiliated faculty, legendary intramural sports teams, and Master’s Teas with world leaders are an incomparable experience.

Bright College Years. In many ways friendship defines the Yale experience. One student sums it up: “It’s about the people, not the prestige.”

Studies.

A Liberal Education, Part I. Yale’s educational philosophy, more than 75 majors, the meaning of breadth, and some startling numbers.

Eavesdropping on Professors. Why being an amazing place to teach makes Yale an amazing place to learn.

Two, Three, Four, Five Heads Are Better Than One. Study groups and why Yalies like to learn together.

College Meets University. An undergraduate road map to the intersection of Yale College and the University’s graduate and professional schools.

Next-Gen Knowledge. For Yalies, one-of-a-kind resources make all the difference.

Blue Booking. Yale is one of the only universities in the country that lets you test-drive your classes before you register during what’s known as “shopping period.” Preparing to shop is a ritual in and of itself, signaled by the arrival of the Blue Book, Yale’s College’s catalog of approximately 2,000 courses.

A Liberal Education, Part II. The fruits of a liberal education’s labor — a sampler of innovation from the discovery of vitamins to the invention of the artificial heart and the creation of FedEx overnight delivery.

Eavesdropping on Professors. Why being an amazing place to teach makes Yale an amazing place to learn.

Dispatches from the World. One place you’ll find yourself at Yale is all over the globe. Over and above ordinary financial aid, Yale awards over $3 million for fellowships, internships, and relief from summer earnings obligations in order to guarantee that every students who wishes will be able to work or study abroad.

Places.

Inspired by Icons. Why architecture matters. Among the nation’s oldest universities Yale is the one most firmly defined by its architecture.

State of the Arts. From the digital to the classical, Yale’s spectacular arts options.

Pursuits.

Bulldog! Bulldog! Bow, Wow, Wow! Playing for Yale — The Game, the mission, the teams, the fans, and, of course, Handsome Dan.

Difference Makers. Through Dwight Hall, Yale’s Center for Public Service and Social Justice, students find their own paths to service and leadership in New Haven.

The Daily Show. A slice of Yale’s creative life during one spring weekend.

E.Literati. Why Els are just so darned determined to publish.

Home Grown. How Yale’s sustainability project is changing the world one campus at a time.

Shared Communities. Yale’s tradition of Cultural Houses and affinity organizations and centers.

Keeping the Faiths. Nurturing the spiritual journeys of all faiths.

Noah Webster Lived Here. Bumping into history at Yale.

Nine Squares. The modern university, the cosmopolitan college town.

Elm City Run. On a run from East Rock to Old Campus, one student explains why New Haven is the perfect size.
The Good News about the Cost of Yale.

If you are considering Yale, please do not hesitate to apply because you fear the cost will exceed your family’s means. Yale College admits students on the basis of academic and personal promise and without regard to their ability to pay. Once a student is admitted, Yale meets 100% of that student’s need. As President Levin stated when he announced the new policy, “We are doubling financial aid, reducing the average cost of sending a student to Yale College by over 50%.

Yale made history with its new financial aid policy, reducing the average cost of sending a student to Yale College by over 50%. "

> Families with less than $60,000 in income pay nothing for an admitted child to attend Yale.

> Families earning $60,000 to $120,000 typically contribute from 1% to 10% of total family income.

> The contribution of aided families earning above $120,000 averages 10% of income.

To help families make an initial estimate of their expected contributions, the University’s new Financial Aid Web site includes an online calculator to figure the net cost of attendance. Below are three examples that illustrate family contributions at different income levels for 2009–2010. Parent contributions may vary according to such factors as the number of dependent pre-college aged children and the size of the household. Parent income presented includes taxable and non-taxable sources.

**Examples of Parental and Student Annual Contributions, 2009–2010**

<table>
<thead>
<tr>
<th>Case A</th>
<th>Case B</th>
<th>Case C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parents’ income</td>
<td>$60,000</td>
<td>$90,000</td>
</tr>
<tr>
<td>Parents’ assets</td>
<td>$100,000</td>
<td>$150,000</td>
</tr>
<tr>
<td>Parents’ contribution with one child in college</td>
<td>$2,650</td>
<td>$2,650</td>
</tr>
<tr>
<td>Parents’ contribution with two children in college</td>
<td>$1,350</td>
<td>$1,350</td>
</tr>
<tr>
<td>Student’s contribution</td>
<td>$1,200</td>
<td>$1,200</td>
</tr>
<tr>
<td>Student’s assets, if any</td>
<td>25% of total student assets</td>
<td></td>
</tr>
</tbody>
</table>

Visit [www.yale.edu/financialaid](http://www.yale.edu/financialaid)

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**Creative Team**

Jeff Brenzel, B.A. 1975, Dean of Undergraduate Admissions

Peter Chemer, Admissions Officer

Ayanka Fernando, B.S. 2008, Admissions Officer

Steven M. Griswold, Deputy Provost for Science & Technology; Eugene Higgens Professor of Physics & Applied Physics

Jessie Royce Hill, Admissions Officer and Director of Publications

William A. Segrave, Associate Dean of Admissions, Yale College; Research Scientist and Lecturer, Molecular, Cellular, and Developmental Biology

Kyle Vanderlick, Dean of the School of Engineering & Applied Science; Thomas E. Golden, Jr., Professor of Engineering

**Design:** Pentagram

Michael Bierut, Pentagram. Senior Critic in Graphic Design at the School of Art, and a Senior Faculty Fellow at the School of Management


**Photography:** Lisa Kereszi, M.F.A. 2000, Lecturer and Acting Director of Undergraduate Studies; Photography at the School of Art

Text: Andrea Jarrell

Additional photography and images by: Robert Baty, Wee Dong and Haifan Liu, Sarah Forrest Photography, © Jeff Goldberg / Esto, Michael Marland, Harold Shapiro. Rush University Medical Center, Jan Schroers, Yale Manuscripts & Archives/Yale University Library, and Yale University.

Some of the stories in the Innovation Supplement were adapted from the Yale Bulletin and Calendar "Innovators" supplement written by Daniel Jones and Bill Hathaway and published by the Yale Office of Public Affairs.

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http://www.yale.edu/bulletin/html/grad/the-work-of-yale-university.html